COST- BENEFIT ANALYSIS OF ELECTRONIC TOLL COLLECTION(ETC) SYSTEM IN IRANIAN FREEWAYS (CASE STUDY: TEHRAN-QOM FREEWAY)

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ABSTRACT

This paper focuses on the economic and technical analysis of Electronic Toll Collection(ETC) after investigating the ETC systems in Tehran-Qom and Tehran-Karan freeways in Iran. It should be noted that this paper is based on a study carried out two years ago and according to a more recent research Tehran-Karaj is not a toll road anymore. The most important aspects considered in this paper are reduced fuel consumption, reduced personnel costs, and reduced waste time of passengers. Finally, the economic savings obtained by utilization of such a system in the mentioned freeway is calculated.

KEYWORDS

Electronic Toll Collection(ETC), Road Transportation, Cost-benefit Analysis, ITS

1. INTRODUCTION

Any structure, building or system needs maintenance and rehabilitation which are of course costly. Highways and roads are also not an exception. From the very past, the construction, extension, maintenance and operating costs of highways, roads, bridges and tunnels were collected directly or indirectly. In the older indirect method, the expenses are compensated either by tax payment on fuel or rubber, or by budget allocation from the national income. The shortcoming of this method is that a number of tax payers, who do not use some of the roads and carriageways, have to pay extra money. However, in the other system, called direct method, the tolls are taken directly from the drivers passing that road or street. In the common traditional method that is currently experienced in Iran, the road is blocked by some barriers in the route and the vehicles are permitted to pass the road after they pay the toll (in cash or by ticket). Although in this method the tolls are directly collected from the users, the mobility of vehicles is interrupted which in turn results in longer travel time, higher fuel consumption and increased pollution level in that region. Another method that is commonly used today in industrial and advanced countries is the Electronic Toll Collection (ETC) in roads and carriageways. In this method, tolls are collected using electronic equipment on road sides and with no speed reduction or vehicle stopping. This method will bring about intercity traffic calming, reduced travel time, fuel consumption reduction, and unified monetary network. Among the several advantages of the ETC method, the following can be mentioned:
-Reducing fuel consumption by removing the need to stop and eliminating deceleration/acceleration time,
-Reducing the number of personnel required for toll collection,
-Reducing air pollution,
-Passenger convenience,
-Reducing cash flow and unifying the monetary system.

2. STRUCTURE OF ETC SYSTEM

An ETC system consists of three sections: Automatic Vehicle Identification (AVI), Automatic Vehicle Characterization (AVC) and Vehicle Enforcement System (VES).

AVI: In this section, vehicles are identified. This system includes roadside equipment and inside-vehicle tags. There is a receiver in the passing route of vehicles that communicates with the tag installed on the rear-windshield and reads the vehicle information. The electromagnetic waves used for transferring the data are generally Radio Frequency (RF) wave type. The reason is that there is less data transfer error in fuggy and rainy weather, when using such frequencies. Of course, there are other methods of data transferring, such as optical, laser, inductive, etc. but none of them have the efficiency of Radio Frequency waves.

There are two types of tags: normal and smart. Normal tags are either fixed (read-only) or changeable (read/write). The information and data in read-only tags cannot be changed and their data can only be read. However, the information and data in read/write tags can be altered. For instance, the latter tags can save the location and time of passage from a toll route. Both read-only and read/write tags have two active and passive types. In the active type, tag sends the information to antenna, while in the passive type the data reaches antenna through the reflected waves. Passive system has less data transfer range as compared to active type. Data transfer frequency is 900 to 925 MHz in USA and 2.45 or 5.8 GHz in other parts of the world. These tags have 128 to 512 bits of Erasable Programmable Read-Only Memory (EPROM) or Electronic Erasable Programmable Read-Only Memory (EEPROM). Some of these tags can be upgraded to 16 mega bits of memory. Also, these tags have batteries with 5- to 10-year life. Standards supported by such tags are Crescent HELP, ATA 5/16/90, ISO 10374.2, AAR S-918-92, ANSI MH5.1.9-1990, California Title 21. Other tags, called smart tags, are placed inside the vehicle and are able to send the vehicle, customer and account balance information to the receiving antenna. Some portions of the tag information are fixed (such as vehicle and customer data), while others are updatable (such as balance information). These tags have a processor to calculate and estimate the balance each time the tag is used. They are able to simultaneously send the information and data to the toll antenna and receive the required information (e.g. the location and toll amount). Also, they are active tag types with a functional frequency range similar to normal tags. Smart tags are installed on a board with 16 to 64 Kbits of memory types EPROM, EEPROM, Read-Only Memory (ROM) or Random Access Memory (RAM) together with a battery with about two-year life. Figure 1 is a schematic of the location where antennas are installed and the way they communicate with tags.

AVC: This section is responsible for vehicle classification. Obviously, tolls should be dependant on vehicles' weight and size. Therefore, it is necessary to use equipment for identification of vehicle classes (passenger car, minibus, bus, two-axle lorry, and multi-axle lorry). Various equipment are installed in a toll route to identify vehicle classes. Among these equipment, the followings can be named:

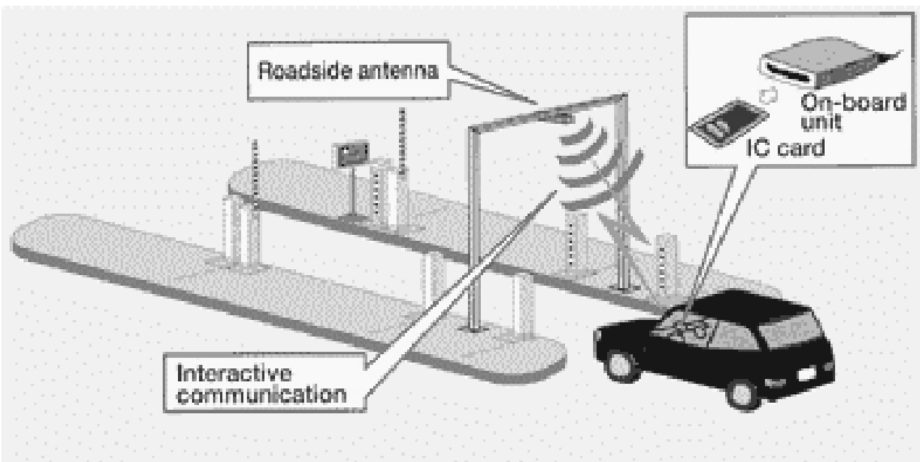

Figure 1 – Schematic of communication between in-vehicle tag and roadside antenna

Coils: coils, which are installed in vehicles' travel lane on the pavement, are able to estimate the metal mass of vehicle.

Treadles: They are installed inside the frame line on the pavement and are able to determine the number of wheels and axles in a vehicle. There are different types of treadles including: electromechanical, flexible resistors, optical, and piezoelectric.
Weigh-in-motion scales: This equipment has the responsibility of evaluating vehicles' weight while they are moving. Different types of such scales exist including: metal plates, capacitor strip and piezoelectric sensors.
Optical beam: It is an optical beam that intercepts the pathway of vehicles in order to estimate their length. This method has some errors involved due to the fact that emitted light can pass through the windows of vehicle and cause a mistake in calculating its length.
Light curtain: This method, which consists of several light beams to intercept the negotiating line of vehicles, can precisely determine the shape and dimensions of vehicles.
Scanning equipment: Such equipment is supposed to scan vehicles with the purpose of specifying their dimensions. They can be either audio, laser, or infrared.
Video processing: This is a new method in which video images of vehicles are taken and used for accurate automatic determination of vehicle classes taking advantage of modern software.
VES: Today it is possible for the vehicles passing a toll road not to have authorized tags, to have insufficient account balance for the required toll, or to have invalid tags. In such a case the violating vehicle should be identified and face legal action. To identify and record violations, special cameras are used to take photographs from the violating vehicle's license plate. Then a ticket would be sent to the violator's living address. Recently, in these systems image processors are also used for automatic identification of vehicle license plates.
The whole system in a network is monitored by a central computer connected to the monetary network of the country. Figure 2 shows a lane equipped with ETC and the location of equipment.

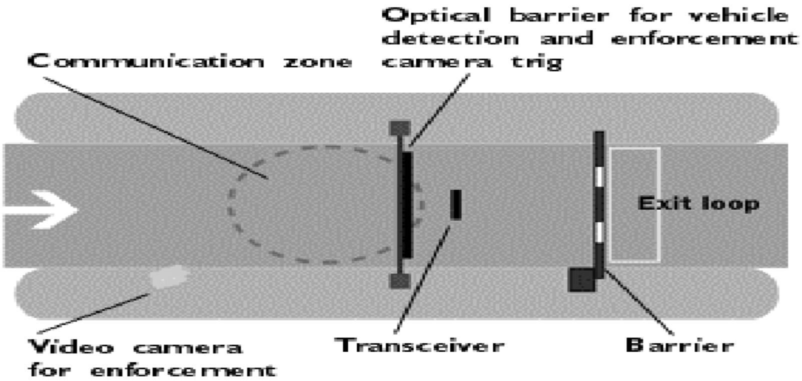

Figure 2 – Schematic of the location of equipment in a lane equipped with ETC

3. THENICAL AND ECONOMICAL ANALYSIS OF ETC METHOD

Savings from installation and commissioning ETC equipment can be divided into three following subgroups: fuel savings, savings from ticket elimination and reduction of staff dedicated to stations, and savings from reduction in travel time. These savings are calculated for Tehran-Karaj and Tehran-Qom routes which will be presented in the following sections. It should be noted that currently there are no toll stations in Tehran-Karaj route and the calculations are based on the assumption that what would be the total costs if the traditional toll booths were used. The tolls for this route are collected using indirect method, which as mentioned in the introduction, is not a suitable method for toll payment at all.

3.1. Savings due to reduction in fuel consumption

In order for the financial-economical analysis of electronic toll collection in Iran with the aim of reducing fuel consumption, first the general analysis and calculations will be presented. Then the amount of fuel consumption reduction and its financial benefits in Tehran-Karaj and Tehran-Qom routes will be discussed as an example.

Due to the fact that ETC system allows for toll collection while the vehicles pass with normal speeds, the decrease/increase speed and stop incidents which lead to extra fuel consumption, will be eliminated. Fuel consumption reduction is calculated as the difference between fuel consumption in the current toll collection method and that of ETC system. Saving in fuel consumption is calculated using the following procedure:

1. Average fuel consumption per hour is calculated for a vehicle.
2. Total reduced travel time when replacing the current method with the ETC system is calculated.
3. Saving in fuel consumption is obtained by multiplying the above two values.

To do so, the following steps should be taken:

1. The number of vehicles using ETC system in one day (24 hours) is calculated using the following equation:

$$ETC_n = TV_n \text{ x } i_{ETC} \tag{1}$$

where:
TV_n : Total number of vehicles that pass a tollbooth in a day (24 hours)
i_{ETC} : Percent vehicles using the ETC system

2. Reduced travel time for a vehicle due to utilization of ETC system instead of the current method, is calculated as follows:

$$T_{etc} = t_{cash} – t_{etc} \tag{2}$$

where:
t_{cash} : Stop time for a vehicle to pay the toll manually
t_{etc} : Payment time for a vehicle in the ETC system with no stops

Reduced time for a vehicle due to elimination of deceleration/acceleration in tollbooth area would be calculated using the following equation:

$$T_{al} = t_a + t_l – t \tag{3}$$
$$t_a = d_a / v_d \tag{4}$$
$$t_l = d_l / v_d \tag{5}$$
$$t = d /v \tag{6}$$

where:
t_a : Tollbooth approach time. It is calculated as the time it takes for the vehicle to stop in front of the booth, from the moment it starts to decelerate.
t_l : Tollbooth leave time. It is calculated as the time it takes for the vehicle to reach its normal speed, from the moment it leaves the booth.
t : Travel time between two ramps with normal speed
d_a, d_l : Distance required for a vehicle to decelerate from normal speed until it stops or to increase speed to reach normal speed which is called ramp.
v_d, v_a : Average speed of the vehicle during deceleration or acceleration period
d : Distance between the ramp before and after tollbooth
v : Average normal speed of the vehicle

If T_q is the reduced time for a vehicle due to elimination of waiting in a queue, the total reduced time that is a function of payment time, deceleration, acceleration, and waiting in a queue, would be:

$$TS = T_{etc} + T_{al} + T_q \tag{7}$$

3. Fuel consumption should be considered in two ways:

Average fuel consumption per hour for a vehicle while moving:

$$FC_v = v/d_f \tag{8}$$

Where d_f is the average distance a vehicle has passed using one litre fuel.

If FC_v is taken as vehicle fuel consumption per second during stop time, the total fuel saving for a vehicle in a day can be calculated as:

$$FS_v = FC_v \times (T_{etc} + T_{al}) + FC_i \times T_q \quad (9)$$

FS is the total fuel saving in a day that if multiplied by the number of days in a year, would give the total fuel saving per year.

Therefore, the total fuel saving per year can be calculated as:

$$FS = 365 \times ETC_n \times FS_v \quad (10)$$

Having the statistics of Tehran-Karaj and Tehran-Qom routes, it is possible to calculate fuel savings as a result of ETC system installation.

Table 1 – Estimated fuel savings when using ETC method instead of traditional system

Item	Tehran-Karaj Route	Tehran-Qom Route
Total number of vehicles per day	120,000	46,900
Percent vehicles estimated to use ETC system	80%	80%
Payment time in manual system (second)	7	7
Payment time in nonstop ETC system (second)	2.5	2.5
Total reduced time when using ETC system (hour)	0.00125	0.00125
Vehicle average normal speed (km/h)	80	80
Distance between before and after tollbooth ramp (km)	0.37	0.37
Vehicle average speed during deceleration/acceleration (km/h)	40	40
Tollbooth approach or leave time (hour)	0.00925	0.00925
Travel time between two ramps with normal speed (hour)	0.00925	0.00925
Reduced time due to elimination of deceleration/acceleration (hour)	0.00925	0.00925
Average waiting time in a queue for a vehicle in manual system (second)	240	240
Fuel consumption in one-second stop (litre)	0.000333	0.000333
Total waiting time in a queue per day in manual system (hour)	0.06667	0.06667
Total reduced time per day (hour)	0.077167	0.077167
Fuel consumption per 100 km (litre)	8	8
Average distance traveled using one litre fuel (km)	12.5	12.5
Average fuel consumption per hour for a vehicle (litre)	6.4	6.4
Total fuel consumption per day (liter)	0.15	0.15
Total fuel consumption per year for a vehicle (litre)	53.7	53.7
Total fuel consumption per year (litre)	5,155,200	2,014,824
Total savings per year due to reduced fuel consumption (rials)	8,763,340,000	3,425,200,800

3.2. Savings due to ticket elimination and manpower costs reduction

In the following table, the number of staff dedicated to traditional tollbooths and ETC stations are presented and personnel costs are compared based on monthly income. It is noteworthy that personnel costs in Tehran-Karaj and Tehran Qom routes are similar; however, ticket prices are proportionate to vehicle passage. Once again it should be clarified that there are no toll stations in Tehran-Karaj route at the time being and personnel costs as well as ticket prices are calculated assuming that tollbooths are present.

Table 2 - Estimated savings in constant costs when using ETC method instead of traditional system

Item	Tehran-Karaj Route	Tehran-Qom Route
Number of staff in traditional system	63	63
Annual income of an employee in traditional system (rials)	15.2×10^6	15.2×10^6
Personnel costs in traditional system (rials)	960×10^6	960×10^6
Number of staff in ETC system	12	12
Annual income of an employee in ETC system (rials)	40×10^6	40×10^6
Personnel costs in ETC system (rials)	480×10^6	480×10^6
Annual savings in ETC system due to personnel costs (rials)	480×10^6	480×10^6
Constant cost including ticket issuing (rials)	3070×10^6	1200×10^6

3.3. Savings due to travel time reduction

Total savings from travel time reduction and increased passenger time can also be calculated as given in the table below.

Table 3 - Estimated passenger time savings when using ETC method instead of traditional system

Item	Tehran-Karaj Route	Tehran-Qom Route
Total reduced time per day (hour)	0.077167	0.077167
Total annual reduced time for a vehicle (hour)	28.166	28.166
Average number of passengers per vehicle	2.10	2.10
Total annual reduced time for passengers of a vehicle (hour)	59.149	59.149
Total annual reduced time (hour)	5,678,304	2,219,270
Total savings per year due to reduced travel time (rials)*	39.75×10^9	15.5×10^9

* The value of an hour is considered approximately 7000 rials for one passenger

4. CONCLUSION

In the above discussion three economic benefits of installing ETC equipment in toll stations instead of traditional tollbooths was mentioned. In addition, it was declared that tolls in Tehran-Karaj route are collected indirectly through national income which is not a suitable method based on the explanations provided in the introduction. Therefore, installing toll stations in this route is essential and according to this paper using ETC toll stations would be a cost-effective alternative. Moreover, the study showed that replacing traditional tollbooths in Tehran-Qom is economically justifiable. Calculations clarified that installing ETC stations would lead to national savings of 51.583 billion rials in Tehran-Karaj route and 20.125 billion rials in Tehran-Qom route.

It should be noted that benefits mentioned in this paper are related to direct payments however, ETC systems have some indirect benefits such as air pollution reduction and environmental effects that result in a healthier environment and reduction of hygienic costs. One of the important advantages is longer vehicle life, reduction of transportation costs due to less travel time, increased monitoring capability and highway traffic control, increased precision of surveying activities in highways and other items that explaining and analyzing them is beyond the scope of this paper.

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